

Incidence and severity of respiratory insufficiency detected by transcutaneous carbon dioxide monitoring after cardiac surgery and intensive care unit discharge

Elaine E. Lagow, RN, CCRC, Barbara “Bobbi” Leeper, MN, RN, CCRN, Linda W. Jennings, PhD, and Michael A. E. Ramsay, MD

Patients undergoing coronary artery bypass surgery and/or heart valve surgery using a median sternotomy approach coupled with the use of cardiopulmonary bypass often experience pulmonary complications in the postoperative period. These patients are initially monitored in an intensive care unit (ICU) but after discharge from this unit to the ward they may still have compromised pulmonary function. This dysfunction may progress to significant respiratory failure that will cause the patient to return to the ICU. To investigate the severity and incidence of respiratory insufficiency once the patient has been discharged from the ICU to the ward, this study used transcutaneous carbon dioxide monitoring to determine the incidence of unrecognized inadequate ventilation in 39 patients undergoing the current standard of care. The incidence and severity of hypercarbia, hypoxia, and tachycardia in post-cardiac surgery patients during the first 24 hours after ICU discharge were found to be high, with severe episodes of each found in 38%, 79%, and 44% of patients, respectively.

Respiratory complications after cardiac surgery have been shown to result in prolonged hospital length of stays and increased costs of care (1, 2). A retrospective review of these patients at our institution demonstrated a 5% to 10% early intensive care unit (ICU) readmission rate with the main diagnosis of respiratory failure. If the patients at risk could be identified by better monitoring, perhaps an earlier intervention could be made that would prevent the need to return to the ICU and the increased costs involved. To that end, this prospective observational study analyzed the adequacy of ventilation and oxygenation by measuring transcutaneous carbon dioxide (tcpCO₂) and peripheral hemoglobin saturation (SpO₂) when the postoperative cardiac surgery patient was initially admitted to the ward from the ICU.

METHODS

Institutional review board approval was obtained at Baylor University Medical Center at Dallas to enroll patients undergoing major open cardiac surgery between October 2009 and October 2012. All patients were between the ages of 18 and 85. Patients were excluded for any prior use of an investigational device/drug within the last 30 days, any condition that would require extensive time off the nursing unit during the first 24

hours (e.g., hemodialysis), allergy to the ear probe, or an inability to undergo all protocol requirements. Prior to enrollment, all patients were screened for study eligibility and their medical history was reviewed. Informed consent was obtained preceding any study procedure, and 51 patients were enrolled.

All patients received a standard general anesthetic appropriate for cardiac surgery and were transported to the ICU immediately postoperatively. Following overnight or appropriate recovery in the ICU, patients were discharged to the cardiac telemetry ward, where they received the usual standard of care. To meet discharge criteria, all patients had to be separated from ventilatory support and require only supplemental oxygen via nasal cannula. The goals of this study were to determine the incidence of unrecognized respiratory depression during usual and customary care of these patients, and also to determine how well patients tolerated the sensor and how secure it was following placement. Therefore, the data obtained from the device were not made available to the caregivers, including both the physicians and the bedside nurse, but were recorded and reviewed later.

Upon arrival to the telemetry floor, a TOSCA 500[®] or TCM TOSCA[®] (Radiometer Medical ApS, Brønshøj, Denmark) monitor was attached to an earlobe of the patient. The TOSCA is approved by the US Food and Drug Administration for simultaneous continuous monitoring of tcpCO₂, functional oxygen saturation, and pulse rate in adults and children (Post Market Approval #K063434). The monitor provides information on both oxygen saturation and carbon dioxide levels (3–7). The tcpCO₂ reading from the TOSCA has been shown to correlate well with arterial carbon dioxide levels (PaCO₂) (8–10). The TOSCA probe is attached to the earlobe and is heated to facilitate blood flow and capillary vasodilation below the sensor. The sensor temperature may be set between 37°C and 45°C in

From Baylor University Medical Center at Dallas (Lagow, Leeper, Ramsay), and the Annette C. and Harold C. Simmons Transplant Institute, Dallas, Texas (Jennings).

Corresponding author: Michael A. E. Ramsay, MD, FRCA, Department of Anesthesiology and Pain Management, Baylor University Medical Center at Dallas, 3500 Gaston Avenue, 2nd Floor, Roberts Hospital, Dallas, TX 75246 (e-mail: docram@baylorhealth.edu).

steps of 0.5°C with an accuracy of $\pm 0.2^\circ\text{C}$. The manufacturer recommends that the probe be heated to 42°C to adequately enhance blood flow, with a change in probe site every 12 hours to prevent thermal burn (9, 11). Two models of the TOSCA monitor were utilized in this study, the TOSCA 500 and the TCM TOSCA. The TOSCA 500 monitor stores all measured patient results every 3 seconds and was used earlier in the study, followed by the TCM TOSCA model, which stores all measured patient results every 10 seconds. Computer software enables data collected from the monitor to be exported to other programs. Therefore, SpO₂, tcpCO₂, and heart rate data every 3 or 10 seconds were available for analysis.

Hypercarbia for this study was classified as mild (tcpCO₂ 42–49 mm Hg), moderate (tcpCO₂ 50–59 mm Hg), or severe (tcpCO₂ ≥ 60 mm Hg). Hypoxia for this study was classified as mild (SpO₂ 91%–85%), moderate (SpO₂ 84%–80%), or severe (SpO₂ $\leq 79\%$). Tachycardia for this study was classified as mild (pulse rate 80–90 bpm), moderate (pulse rate 91–119 bpm), or severe (pulse rate ≥ 120 bpm). Events for the study were cataloged singularly into events of tcpCO₂ ≥ 60 mm Hg, SpO₂ saturation $\leq 79\%$, and pulse rate ≥ 120 bpm. Events were also cataloged with combinations of SpO₂ saturation of $\leq 79\%$ with a tcpCO₂ ≥ 60 mm Hg; SpO₂ saturation of $\leq 79\%$ with a pulse rate ≥ 120 bpm; and SpO₂ saturation $\leq 79\%$ with pulse rate ≥ 120 bpm plus a tcpCO₂ ≥ 60 mm Hg.

RESULTS

A total of 51 patients were enrolled in the study, 15 women and 36 men, with a mean age of 63 years. Forty-five of the patients were white or Hispanic and six were black. Twelve of the 51 patients were not included in the final analysis: three withdrew consent prior to the probe being applied; one was in the ICU for an extended period of time and was transferred directly to the rehabilitation hospital, bypassing the telemetry unit; and the remaining eight patients experienced machine malfunction and/or staff error. Twenty-six of the patients were attached to the TOSCA 500 for up to 24 hours from December 2009 through January 2011. Thirteen were attached to the TCM TOSCA for up to 24 hours from March 2012 through October 2012.

The total number of actual recorded hours for all 39 patients was 713 hours: 18% of patients had ≤ 9 hours, 31% had >9 to <20 hours, and 51% had ≥ 20 hours. The tcpCO₂ sensor was functional for a mean of 74% of potential recorded time. The O₂ saturation sensor was functional for a mean of 90% of this time. Twelve patients who were connected to the monitors asked to discontinue the study due to the inconvenience of the probe or annoyance with the alarm on the machine. The total time

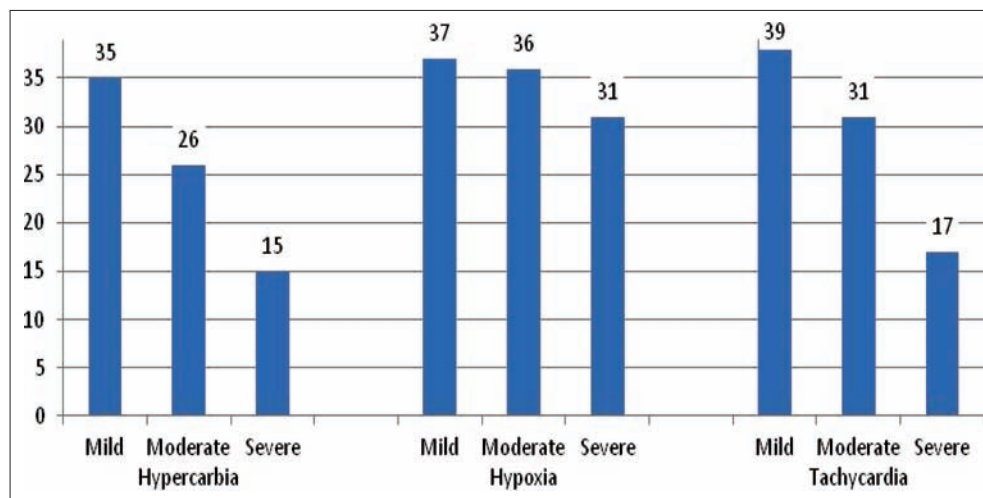


Figure 1. Number of patients experiencing hypercarbic, hypoxic, and tachycardic events among 39 patients monitored after cardiac surgery using transcutaneous carbon dioxide monitoring in the intensive care unit.

monitored in this group was 141 hours. There were three files that recorded only the first 12 hours.

One patient returned to the ICU with respiratory distress the third day after transfer to the ward. The study was designed to monitor only the first 24 hours posttransfer and therefore did not detect this event when the data were reviewed. However, the patient did exhibit periods of desaturation during the first 8 hours posttransfer, and the oxygen delivery rate was increased from 4 L per minute via nasal cannula to 5 L per minute per nursing unit protocol.

Figure 1 summarizes the number of hypercarbic, hypoxic, and tachycardic events, and Table 1 summarizes the duration of these events. Overall, there were 41 moderate or severe hypercarbic events. The total duration of tcpCO₂ ≥ 60 mm Hg was 39.03 ± 72.24 (SD) minutes, ranging from 0.05 to 280 minutes, with a median of 13 minutes. The total duration of tcpCO₂ 50 to 59 mm Hg was 129.6 ± 218.1 minutes, ranging from 0.05 to 1092 minutes with a median of 67 minutes. The total duration of SpO₂ saturation $\leq 79\%$ in patients experiencing hypoxic episodes was 4.4 ± 9.9 minutes, ranging from 0.1 to 49.7 minutes with a median of 1.1 minute. A pulse rate

Table 1. Median duration of hypercarbic, hypoxic, and tachycardic events in 39 patients after cardiac surgery based on transcutaneous carbon dioxide monitoring in the intensive care unit

Event	Number of patients with at least one event	Median total duration (minutes)
Mild hypercarbia (42–49 mm Hg)	35	303
Moderate hypercarbia (50–59 mm Hg)	26	67
Severe hypercarbia (≥ 60 mm Hg)	15	13
Severe oxygen desaturation ($\geq 79\%$)	31	1.1
Severe tachycardia (≥ 120 bpm)	17	3.1

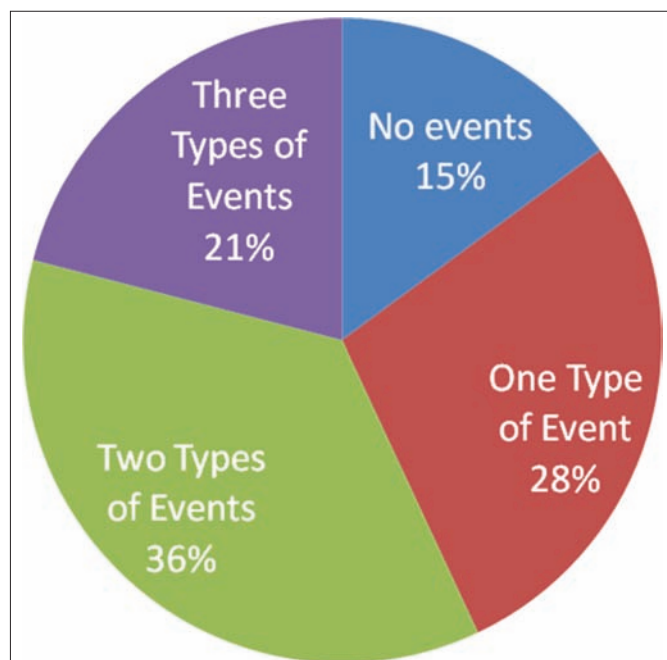


Figure 2. Percentage of patients experiencing severe-only hypercarbic, hypoxic, and tachycardic events after cardiac surgery based on transcutaneous carbon dioxide monitoring in the intensive care unit.

≥ 120 beats/minute occurred in 17 patients, with a total duration of 11.8 ± 20.5 minutes, ranging from 0.1 to 78.0 minutes with a median of 3.1 minutes. Thirty-one percent of these tachycardic patients had a history of atrial fibrillation. As shown in Figure 2, 21% of the patients experienced all three symptoms of severe hypercarbia, hypoxia, and tachycardia in the first 24 hours after discharge from the ICU.

DISCUSSION

We presented results of 39 postoperative cardiac surgery patients during their first 24 hours following transfer from the ICU to the telemetry floor, showing that the incidence and severity of hypercarbia, hypoxia, and tachycardia were high. The continuous monitoring of tcpCO_2 , SpO_2 , and pulse rate provides earlier identification of severe respiratory depression, and therefore would lead to earlier intervention and possibly prevent a return to the ICU. Monitoring is particularly important for patients with a history of pulmonary disease, which may increase postoperative complications and ICU stay. A well-tolerated patient monitoring technology that accurately, automatically, and continuously tracks transcutaneous carbon dioxide levels has the potential to greatly improve the timeliness of a response to a failing patient and improve patient safety and outcomes. The episodes of severe hypoxia, hypercarbia, and tachycardia detected in this study indicate a need for improved monitoring of this patient population.

There were several limitations to our study. First, although 51 patients agreed to participate, we were able to analyze data for only 39 patients. Of those 39, approximately 76% of potential monitored hours were captured. The study monitor TOSCA 500 was upgraded to the TCM TOSCA during the trial. Several patients asked to have the monitor removed early due to continued alarming and comfort level being restricted due to “one more wire” being attached to them. The monitor may have been better tolerated by patients if it were wireless. Some of the technical problems encountered may have been avoided with better education for the nursing staff.

The clinical significance of our findings will need to be determined by a larger study, where the monitor information is provided to the nurses and an intervention protocol put in place. Monitoring tcpCO_2 , SpO_2 , and pulse rate through a single sensor could provide an advantageous and convenient method of early detection of potential severe respiratory depression.

Acknowledgments

Funding for this study was wholly provided by the Cardiovascular Research Foundation of the Baylor Heart and Vascular Institute. The monitors were provided by Radiometer (Brønshøj, Denmark).

1. Ng CS, Wan S, Yim AP, Arifi AA. Pulmonary dysfunction after cardiac surgery. *Chest* 2002;121(4):1269–1277.
2. Weissman C. Pulmonary complications after cardiac surgery. *Semin Cardiothorac Vasc Anesth* 2004;8(3):185–211.
3. Eberhard P, Gisiger PA, Gardaz JP, Spahn DR. Combining transcutaneous blood gas measurement and pulse oximetry. *Anesth Analg* 2002;94(1 Suppl):S76–S80.
4. Bernet-Buettiker V, Ugarte MJ, Frey B, Hug MI, Baenziger O, Weiss M. Evaluation of a new combined transcutaneous measurement of PCO_2 /pulse oximetry oxygen saturation ear sensor in newborn patients. *Pediatrics* 2005;115(1):e64–e68.
5. McBride ME, Berkenbosch JW, Tobias JD. Transcutaneous carbon dioxide monitoring during diabetic ketoacidosis in children and adolescents. *Paediatr Anaesth* 2004;14(2):167–171.
6. Dullenkopf A, Bernardo SD, Berger F, Fasnacht M, Gerber AC, Weiss M. Evaluation of a new combined SpO_2 /Ptc CO_2 sensor in anesthetized paediatric patients. *Paediatr Anaesth* 2003;13(9):777–784.
7. Kagawa S, Otani N, Kamide M, Gisiger PA, Eberhard P, Severinghaus JW. Initial transcutaneous PCO_2 overshoot with ear probe at 42 degrees C. *J Clin Monit Comput* 2004;18(5–6):343–345.
8. Rohling R, Biro P. Clinical investigation of a new combined pulse oximetry and carbon dioxide tension sensor in adult anaesthesia. *J Clin Monit Comput* 1999;15(1):23–27.
9. Gisiger PA, Palma JP, Eberhard P. OxiCarbo, a single sensor for the non-invasive measurement of arterial oxygen saturation and CO_2 partial pressure at the ear lobe. *Sens Actuators B Chem* 2001;76(1–3):527–530.
10. Parker SM, Gibson GJ. Evaluation of a transcutaneous carbon dioxide monitor (“TOSCA”) in adult patients in routine respiratory practice. *Respir Med* 2007;101(2):261–264.
11. Radiometer Basel AG. *TOSCA 500 Operating Manual for USA*. Basel, Switzerland, Radiometer Basel, June 2007.